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TITLE

A method for manufacturing a nanostructure in-situ, and in-situ manufactured nanostructure devices.

TECHNICAL FIELD

The present invention relates to a method for manufacturing a nanostructure in-situ at a predetermined point on a supporting carrier, and also to such a nanostructure device. In addition, the invention relates to electronics devices comprising a nanostructure made according to the method of the invention.

BACKGROUND OF THE INVENTION

Nanostructures, for example in the shape of tubes, so called nanotubes, are structures which offer a number of new and interesting functionalities in, for example, the field of electronics. At present, however, there are difficulties associated with the manufacturing of nanostructures. Nanotubes, for example, are at present produced by means of a variety of procedures, which all have the common drawback that the nanotubes produced in these ways need a significant amount of postprocessing, and also need additional manipulation in order to be incorporated into devices.

DISCLOSURE OF THE INVENTION

The purpose of the invention is thus to solve the mentioned drawbacks of contemporary nanostructure technology, with a non-exclusive emphasis on nanotubes.

This purpose is achieved by a method for manufacturing a nanostructure in-situ at at least one predetermined point on a supporting carrier, which method comprises the steps of choosing a suitable material for a substrate to be comprised in the carrier, creating said substrate, and preparing a template on the substrate, wherein the template covers said predetermined point. The template is given a proper shape according to the desired shape of the final nanostructure, and a film of nanosource material with desired thickness,

width and length is caused to be formed on the template. At least a part of the film of nanosource material is caused to restructure from a part of the template, thus forming the desired nanostructure at the predetermined point.

Said restructuring is in the form of a reassembling on the atomic scale of the nanosource material, resulting in qualitatively new properties relative to the properties of the nanosource material prior to the restructuring, said new properties being manifested in an altered, pre-defined response to external fields or forces.

The expression "qualitatively new properties" should here be taken to mean such fundamental changes in physical and/or chemical properties as, for example, a material which was transparent previous to the restructuring transitioning into being opaque, a conducting material becoming non-conducting, a magnetic material becoming non-magnetic, or materials changing optical and conduction responses by an effective restriction of the electron dynamics to lower dimensions, etc. Other examples of such transitions will be apparent to the man skilled in physics and/or chemistry.

Said template preferably comprises two areas which have different properties with respect to their interaction with the nanosource material. In one embodiment of the present invention, this is done by one of the areas having stronger adhesive properties than the other with respect to the nanosource material.

By means of the method of the invention, virtually any nanostructure can thus be manufactured in-situ on a carrier, with the desired final shape of the nanostructure being obtained by giving the template the proper shape according to the desired shape of the nanostructure. The template may thus serve both as an aligning structure for the nanostructure, and as a bonding material for attaching the nanostructure to the carrier.

The invention thus also offers a nanostructure device, comprising a carrier and a nanostructure positioned on said carrier, said nanostructure extending along a predetermined path on the carrier, with the device additionally comprising an aligning structure, which aligns the nanostructure along said predetermined path on the carrier., the device also comprising a layer of material positioned on the carrier, said material being a bonding material for attaching the nanostructure to the carrier, which also serves as an aligning structure for the nanostructure.

In addition, the invention makes it possible to manufacture electronics devices, for example semiconducting devices, comprising nanotubes.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described in closer detail below, with the aid of the appended drawings, in which:

Fig 1a-1e schematically shows the main steps in a manufacturing process according to the invention,

Fig 2 shows a nanotube manufactured according to the invention, along the line II-II in fig 1,

Fig 3a and 3b show other views of fig 1 and 2, respectively, and

Figs 4 a-b and 5 a-b show the integration of a nanotube according to the invention in an electronics device, and

Fig 6 shows a specific example of a nanosource material, and

Fig 7a-b, 8 and 9 show nanotube semiconductor devices which can be manufactured with the aid of the invention.

EMBODIMENTS

In fig 1, the main steps in a process according to the invention are shown. In order to facilitate the understanding of the invention, an embodiment of the invention in which a specific nanostructure, a nanotube, is formed, will be described. However, it should be kept in mind, and will become apparent to

one skilled in the art, that a large number of different nanostructures can be formed using the present invention.

The main steps of the illustrative process will first be described briefly, following which a more detailed description of some of the steps will be given.

The main steps are as follows:
A material is chosen for a substrate 110, which will act as a carrier. There are two points, A and B on the substrate 110, which it is desired to connect via a nanostructure, in this case a nanotube, which extends along a predetermined path, in this case the shortest distance, i.e. a straight line, between said two points. however, it should become obvious to one skilled in the art that the invention enables a nanostructure to be designed which will follow more or less any predetermined path on the substrate or carrier.

On the substrate 110, a template 115 is formed, so that the template connects the two points A and B, i.e. the template or at least its edges coincides with the predetermined path. Since the nanostructure that it is desired to shape in this example of an embodiment is a nanotube, the template is given essentially rectangular dimensions, for reasons which will become apparent below. However, if it is desired to have a nanostructure of a different shape, this can easily be accomplished by means of the invention, by shaping the template in a manner according to the shape of the desired nanostructure.

The template 115 preferably comprises a first 120 and a second 130 area, said two areas being distinct from each other in that the material of the areas exhibit different properties in a way which will be described below.

On the template, a film 140 of nanosource material is formed. The materials of the two template areas 120, 130 exhibit different properties towards the nanosource material in their interaction with the nanosource material.

In this particular embodiment, the different interaction with the nanosource material lies in that the materials of the two template areas have different adhesive properties towards the nanosource material, the material of one area having stronger adhesive properties than the other. The significance of the different adhesive properties will become apparent in the next step, which in this example is the so called exfoliation of the film:

At least part of the film 140 is caused to exfoliate, in other words to "lift" at least in part from the template area 115. Due to the different adhesive properties of the different template areas 120,130, if the exfoliation is done in a controlled manner according to the invention, only that part of the film 140 which is formed on the template area 130 which has the weaker adhesive properties towards the film will exfoliate, whereas that part of the film which is formed on the area 120 with the stronger adhesive properties will not exfoliate. Rather, this part of the film will serve as an "anchor' for the part of the film which exfoliates, i.e. a fixed point for the future nanostructure, in this case a nanotube 150, as shown in fig 1e.

It should be pointed out that the exfoliation of the film is a particular case of a more general aspect of the invention: parts of the film are caused to rise from the template, and to form into new structures. The action by the film when the template is shaped to make the film into a nanotube is exfoliation. However, a more general term for this step of the invention is that the film is made to "restructure" from the template, and to then form the desired final shape of the nanostructure.

An important feature of the present invention can be pointed out and emphasized here: the restructuring mentioned is in the form of a

reassembling on the atomic scale of the nanosource material, resulting in qualitatively new properties relative to the properties of the nanosource material prior to the restructuring. These new properties are manifested in an altered, pre-defined response to external fields or forces.

The expression "qualitatively new properties" here refers to such fundamental changes in physical and/or chemical properties as, for example, a material which was transparent previous to the restructuring transitioning into being opaque, a conducting material becoming non-conducting, a magnetic material becoming non-magnetic, etc. Other examples of such transitions will be apparent to the man skilled in physics and/or chemistry. The new properties of the material will be known in advance to those utilising the invention, so that the "post-transition" material will exhibit one or more desired physical or chemical properties.

With renewed reference to fig 1, part of the film 140 will restructure thus from the template by way of exfoliation, and the layer of material 140 will now form the desired nanotube 150, which extends along the predetermined path, i.e. connects the two points A and B. The nanotube 150 is bonded to the substrate or carrier by means of the stronger bonding template area 120. Thus, the template serves both as an aligning structure for the nanotube, and as a bonding structure for it.

Naturally, a number of conditions should be fulfilled in order for the process described above in connection with fig 1 to work in an optimal fashion, said conditions being apparent to one skilled in surface science. For instance, the entire process needs to take place in a controlled environment, so that the materials involved are not contaminated during the process.

In addition, the materials should fulfil the following requirements:

- The substrate material: the material chosen for the substrate should exhibit a desired mechanical strength, and should, in addition, in one preferred embodiment be a material on which the nanosource material can not grow/be deposited. One example of a suitable substrate material in electronics components which can be mentioned is silicon.

- The template material: As mentioned above, two different template materials are used, with different adhesive properties with respect to the nanosource material. One possibility is to use the same basic material for both areas, and to then introduce defects into one of the areas in order to create differing adhesive properties. Examples of such defects are grain boundaries, step edges, dislocations, impurities or line edges. One possible material for the template is, for example, silicon carbide, SiC, or Aluminum Oxide. Other examples of suitable template materials are nickel and/or cobalt.

Another distinct possibility would be to use the substrate as a template area also, and to then introduce defects into the areas intended to have template properties, i.e. stronger or weaker bonding properties, the strength being determined by the material introduced as an impurity, and the amount of that material. Thus, one area of the substrate can act as the stronger bonding material, 'the anchor", and another area of the substrate can be induced with defects which make that area an area with weaker bonding properties, or vice versa.

- The nanosource material: examples of suitable nanosource materials are magnesium diboride, graphite, silicon or boron nitride.

Fig 2 shows, among other things, the nanotube 150 along the line II-II of fig 1, seen in a side view. Thus, fig 2 shows a nanostructure device 200, comprising a carrier 110 and a nanostructure 150 in the shape of a tube positioned on the carrier, where the nanotube 150 connects two points A, B

on the carrier. The device 200 additionally comprises an aligning structure 120, here in the form of the template material 120, but it should be pointed out that other ways of bonding the nanotube to the carrier can be envisioned within the scope of the invention.

However, the device shown in fig 2 comprises a layer 120 of material positioned between the nanotube 150 and the carrier 110, with the material 120 being a bonding material for attaching the nanotube to the carrier. As described above, the material 120 also serves as an aligning structure for aligning the nanotube 150 between the desired points A and B on the carrier, so that the longitudinal extension of the tube coincides with the extension of the aligning structure between the two points on the carrier.

Fig 3a and 3b show other views of fig 1 and 2, respectively. In fig 3a, the substrate 110, and the template 115 are shown, as well as the different areas 120, 130 of the template. On top of the template areas, the film 140 of nanosource will be deposited. By means of fig 3a, it should become apparent that the position, orientation and deformation (by means of the restructuring, in this case the exfoliation) of the future nanotube can be controlled completely by means of the invention, since the orientation and position of the template decides the corresponding parameters of the future nanotube. It should also be mentioned that the shape of the nanostructure can be controlled by means of controlling the shape of the template. This means that although only rectangular templates are shown in this description, it is entirely within the scope of the invention to shape a nanostructure in more or less any desired structure by creating the proper corresponding template.

Fig 3b shows the device of fig 3a, following exfoliation of the film of nanosource material. Thus, in fig 3b, there is a nanotube-which connects two desired points on a substrate, the nanotube being bonded to the substrate by means of a bonding material which was, in this case, also used as a guiding structure for determining the extension and position of the nanotube. The

material of the nanotube is shown as a honeycomb pattern, for reasons which will become apparent later in this description.

The points which are connected by the nanotube can, for example, be electrical contacts, if the nanotube is to be comprised in an electronics device.

The exfoliation of the film of nanosource material, i.e. the step between figs 3a and 3b is preferably carried out by providing additional energy to the film of nanosource material. This can be done in a large number of ways which should be apparent to the man skilled in the field, but one such method which can be mentioned is, for example, by means of a laser beam, an ion beam or an electron beam which illuminates at least part of the film of nanosource material.

Additionally, the exfoliation can be done by means of doping at least part of the material of the film of nanosource material, following its deposition on the template areas.

Furthermore, the additional energy does not need to be supplied in equal amounts over the area of nanosource material, the additional energy can, for example, be provided to a section of that part of the nanosource material which has been deposited on the area of the template which has the weaker adhesive properties.

The nanosource material can be deposited on the template area in a large number of different ways, which as such are known. Some such methods which can be mentioned as examples are sputtering or evaporation of the material.

One of many interesting materials to use as nanosource material is the element carbon, particularly if the nanostructures, in this example tubes, are

to be used for conducting electrical current, i.e. if the nanotube is to be comprised in an electronics component or device. In such an application, it is particularly advantageous if the carbon is deposited on the template in the form of a graphene sheet. Graphene can be defined as single atomic layer graphite. Naturally, although the invention will be described using a film of one graphene sheet, one or more graphene sheets can be used in the film of the invention.

Fig 4a and 4b show how a nanotube made according to the invention, using a graphene sheet as nanosource material, can be integrated into an electronics component or device. Since the nanotube is to be used for conducting current along a predetermined path between two points, contacts for external devices should be incorporated into the nanotube device, which will be explained in connection to figs 4a and 4b.

In fig 4a, the substrate 110 of the previous figures can be seen, as well as the different template areas 130 (weak bond) and 120 (strong bond). However, the difference compared to the previous structures is, as will be evident from the figure, that the template area 120 which has the stronger bond to the nanosource material now comprises two contact areas 120', which can cover or constitute parts of the area 120, for example, as shown in fig 4a, its end areas. Said two contact areas 120' are also suitably arranged so that they will protrude at least slightly from the future nanotube, i.e. in this case they protrude outside the edges of the rest of the template.

In fig 4b, the end result is shown: a sheet of graphene film has been deposited on the template, and exfoliated from it so as to form a tube, in the manner described above. The result is a nanotube 150, which connects two parts on the substrate 110, said two parts in this case being contacts for external devices. Since the resulting device 400 shown in fig 4b is intended to connect electrical current, the material for the contact areas should be electrically conducting, in addition to the (stronger) bonding properties

described earlier. The contact areas 120' can either be formed on a previously formed film of the template material 120, or they can be formed directly on the substrate, to act directly as the bonding and aligning structure for the nanotube, as well as being contact points.

Fig 5 basically shows the same as Fig 4, but in the example shown in fig 5, the nanosource material has been doped, i.e. impurities have been introduced into the graphene sheet, thus giving the formed nanotube different conducting properties as compared to a nanotube formed of pure graphene.

Turning now to graphene as a nanosource material, this material has at least one specific property which makes it extremely interesting for electronics applications: depending on the direction in which the film exfoliates, the graphene tube will exhibit different conducting properties. As shown in fig 6, there are two main directions in which a graphene sheet can be exfoliated, shown with the arrows 11 and 12, thus giving the resulting nanotube different so called chirality. Naturally, the film can be exfoliated in almost any direction, using the proper template shape, thus making it possible to create a nanotube with more or less any chosen chirality.

The direction of exfoliation indicated by the arrow l_1 in fig 6 will give the nanotube a chirality known as "zigzag", and the direction of exfoliation indicated by the arrow l_2 in fig 6 will give the nanotube a chirality known as 99 armchair". In more precise, scientific terminology, the "zigzag" chirality can, in terminology known to those skilled in the field, be referred to as (N,0), where N is an arbitrary integer and the "armchair" chirality can be referred to as (N, N), where N is also an arbitrary integer.

A nanotube with "armchair" chirality will exhibit conducting properties similar to those of a metallic material, i.e. the nanotube will be highly conductive, whereas a nanotube with "zigzag" chirality will exhibit conducting properties similar to those of a semiconducting material.

In other words, using a nanotube consisting of a plurality of sections in its longitudinal direction, with the different sections having been formed by exfoliation of graphene sheets in different orientations, thus giving the different sections different chirality, it is possible to obtain components for a semiconductor device, for example a transistor or a diode.

A step in the making of such a semiconductor device is shown in fig 7a: A template area 710, consisting of, in this case, three different areas 720, 730, 740, has been arranged on a suitable substrate 750. In the manner described earlier, each of the template areas 720, 730, 740 comprise two different "sub-areas" 720'. 720", 730', 730", 740', 740", where the "sub-area" denoted by a single apostrophe, ' ,is an area that has weaker bonding properties with respect to the nanosource material, in this case graphene, than the "sub-area" denoted by double apostrophes ".

As shown in fig 7b, the film of nanosource material, in this case graphene, is deposited on the template areas. In the particular case shown in fig 7b, the object is to form a semiconductor device comprising a nanotube with three different sections in the longitudinal direction of the tube, with the two, outer sections having the conducting properties of a metal, i.e. highly conducting, and the middle section having semiconducting properties.

Thus, "sub-areas" 720 and 740 should, upon exfoliation, form a graphene nanotube with "armchair" chirality, and "sub-area" 730 should, upon exfoliation, form a graphene nanotube with "zigzag" chirality. In fig 7b, a very efficient way of forming nanotube sections according to the invention so that the sections will have different chiralities can be seen: it has been discovered by the inventors of the present invention that the exfoliation will take place in a direction which is essentially perpendicular towards the main extension of the "bonding area" of the template. Thus, a graphene film can be deposited more or less uniformly on a substrate on which different connecting template

areas have been formed, and the exfoliated nanotube sections can still be given desired and different chiralities by virtue of the fact that the bonding areas of the individual template areas exhibit different angles with respect to one another. Thus, this method eliminates the need for depositing graphene sheets with different orientation on the different template areas, and still the same end result is achieved.

When graphene film has been formed on the template areas, exfoliation is then carried out as described above. It can be shown that the different sections bond together as one continuous tube, with "bends" if and where the angles of the bonding areas differ from one another.

The different template areas 720, 730, 740, for the various sections of the nanotube can be formed on the substrate on the same side of the future nanotube, or, as shown in fig 7, on alternating (left-right) sides of the future nanotube, or in other patterns. In addition, the "sub-area" with the stronger bonding properties, 720", 730", 740", can be formed in a straight line on the substrate, or, as shown in figs 7a and 7b, with angles between them that are smaller or larger than 180 degrees.

It should be noted that the conducting properties of the different sections of the nanotube can be affected not only by giving the different sections different chirality: another way is to shape the template areas so that different sections of the nanotube will have different radii, thus leading to different cross-sectional areas, which will affect the conducting properties of the respective sections.

Fig 8 shows the making of two separate semiconducting devices on one and the same substrate, using the method shown in fig 7 and described above, and fig 9 shows the making of a more complex semiconducting device than the one in fig 7, using the method of fig 7.

The invention is not limited to the embodiments which have been described above, but may be varied freely within the scope of the appended claims.